INSTITUTE of
HYDROLOGY

Potential Water Resources for the Kilibasi Area

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1. Introduction

1.1 OBJECTIVES

The study was instigated in response to a request from Minster Agriculture in April 1990 for the Institute of Hydrology to undertake a review of the water resources potential of a group of ranches centred on Kilibasi hill in south-east Kenya. The study was to consider the potential sources of water within a fairly large region loosely bounded by the Mombasa to Nairobi road to the north-east, by the Tanzanian border to the south-west and by the outcrop of the Lower Maji Ya Chumvi beds of the Daruma Sandstone series to the south-east (see Figure 1). The north an east boundary of the study area are roughly defined by the Voi to Taveta road and by Longitude 380 20'E.

The study was undertaken in two phases, the first being a desk study, which was reported on in an Interim report in May 1990. This final report follows from a two week visit to Nairobi and the study area undertaken by Mr F.A.K. Farquharson and Dr E.P. Wright in July.

The terms of reference for this water resources review were of necessity vague as detailed development plans for the study area could not be prepared until the water availability issue had been resolved. Thus the brief for the present work was essentially to investigate the local water resources potential of the group of ranches centred on Kilibasi Hill, and if these appeared limited, to consider other potential sources of water that could possibly be imported into the area. There could be no attempt to investigate such bulk water transfer schemes in detail within the time scale of the study and any proposals would require more thorough feasibility studies and should be subject to a full cost benefit analysis at a later stage.

No specific water demands were to be met, but the primary water demand would be for an increased rural population which would impose livestock and food production demands for water. Thus the proposal is that the area might offer scope for resettlement and such an option would only be possible given adequate water resources. The study could not attempt to identify potential sources of water for any particular development, but could only attempt to quantify the availability of surface and groundwater for the study area.

1.2 EXISTING WATER AVAILABILITY

At present the local population, which has not as far as we are aware ever been accurately quantified, obtains water from a series of small dams, valley tanks and a number of rock catchments on Kilibasi Hill. There are few, if any, productive boreholes or wells in the main part of the study area close to Kilibasi Hill, although a number of boreholes producing potable water exist to the north and west of the hill, and as one moves south-east across the Maji Ya Chumvi series, the number of boreholes containing potable water increases.

Geological sketch map with borehole locations in Taita - Kilibasi Study Area

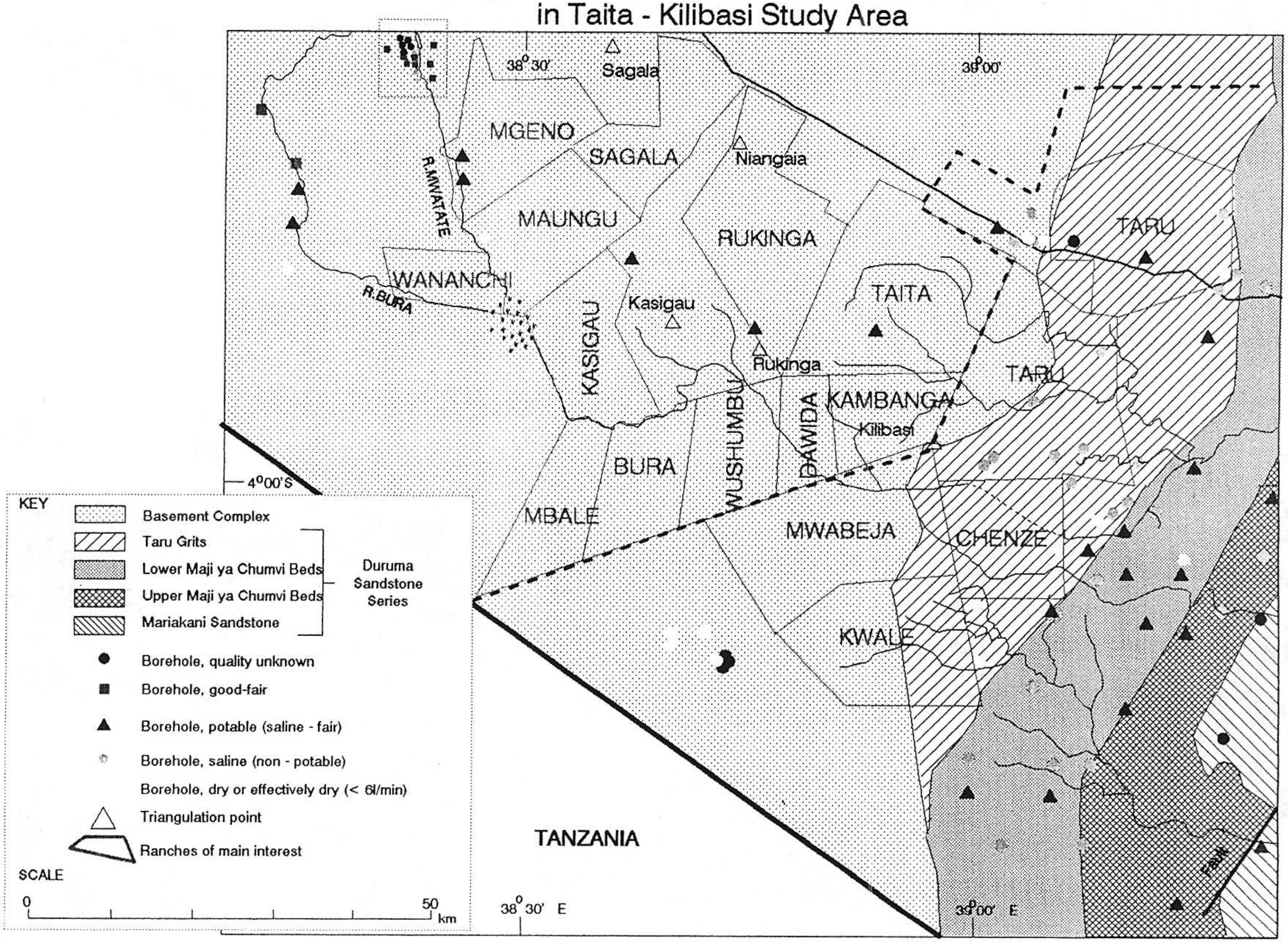


Figure 1

Geological sketch map with borehole locations in Taita - Kilibasi Study Area

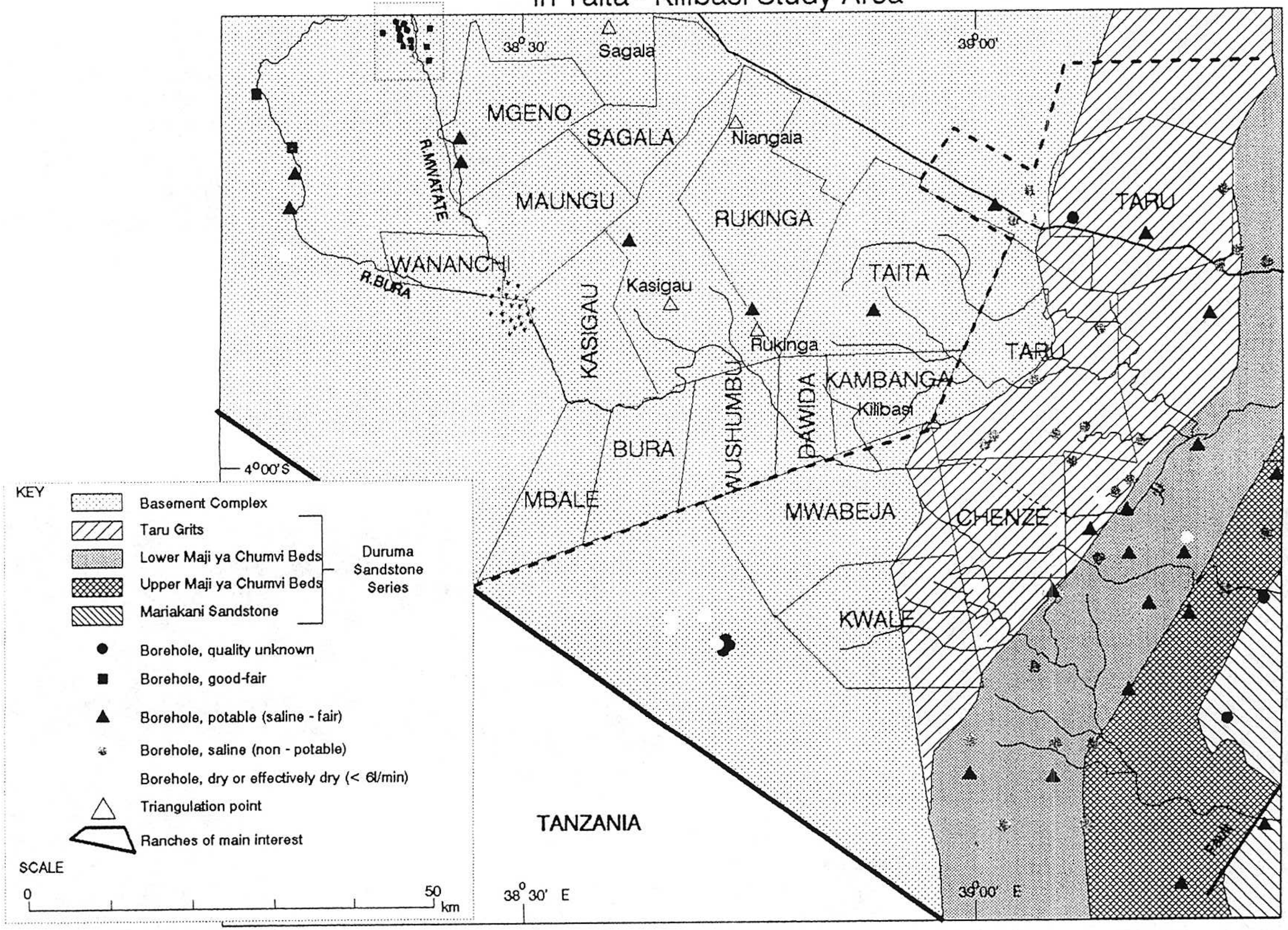


Figure 1

Two major dams exist within the area at Lukakani and Mblini and a third dam at Nyalani is just outside of the area. These are shown on Figure 2. These dams were built in about 1953 and show signs of neglect. In particular, there has been significant damage to the dam embankment at Lukakani and Mblini by animal tracks, and the spillway at Nyalani has been eroded by flood water some years previously and the reservoir capacity has been significantly reduced accordingly. There is a need to rehabilitate these dams in order to improve their yield, and such rehabilitation could be achieved fairly cheaply.

These three dams form conventional reservoirs where the dam is constructed in the main valley channel such that all flows may be captured. The dams require effective spillways so that once the reservoir is full, excess inflow may safely be passed downstream. The spillway channel must be protected against scour by stone or rock facings, and it is this that has failed in Nyalani dam.

A number of smaller reservoirs exist throughout the study area, but these are essentially valley tanks rather than conventional reservoirs in that the embankment does not span the river valley but bounds a low-lying area of the valley to one side of the main water course. Water is diverted into the tank from the river under gravity until the tank becomes full at which time excess river flow continues down the main water course. The structure needs no spillway as the embankment crest level is constructed to a level of a few feet above the maximum flood water level expected in the main river channel. Thus even during major floods the embankment will not be overtopped. Such valley tanks are cheap to construct but will in general not capture as much of the available runoff as a conventional reservoir as some flow will escape down the natural channel. In general, valley tanks within the region dry up towards the end of the dry season.

There are a number of valley tanks within the study area, particularly on Taru ranch, where dams are sited at Dulolo, Busho and two at Ndavako.

1.3 WORK UNDERTAKEN

A visit was made to Nairobi between 20 July and 3 August 1990 by Mr Farquharson and Dr Wright, during which time a six day visit to the general study area was undertaken.

Within the short time scale of the study, only limited collection and analysis of data was possible, although the work undertaken was appropriate for the pre-feasibility studies proposed. The authors are grateful for the assistance provided by Mr Mike Lane, a local hydrologist who collated much of the basic rainfall, riverflow and borehole data for us prior to our arrival. Mr Lane also provided valuable support during the course of the visit, particularly facilitating access to two important previous reports that could not be obtained elsewhere. Acknowledgement must also be made to Mr P. Van Dongen who provided a copy of the Draft Final Report on the water resources of the Kwale hinterland by Groundwater Survey (Kenya) Ltd, following permission being granted by MoWD.

Location of raingauges and dams

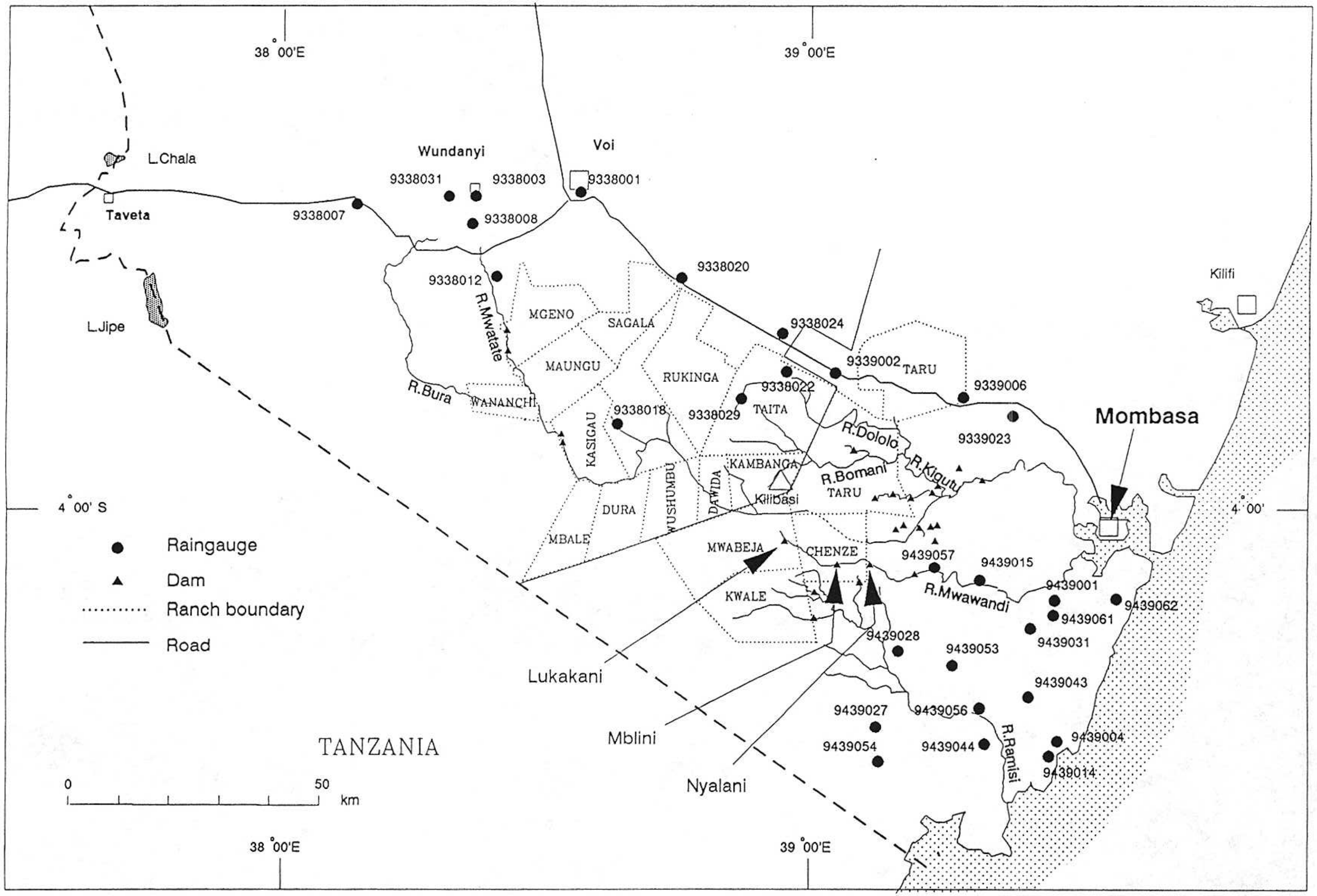


Figure 2

2. Background

2.1 PHYSIOGRAPHY

The area of main interest is contained within the Taita lowlands to the south of the Taita Hills, and the west side of the Kwale hinterland, approximately west of longitude 39'20" East. It is composed predominantly of low-lying plains at an elevation of some 800 m in the north-west decreasing to below 250 m in the south-east. The regional land slope is less than 1% and maximum slopes rarely exceed 5%, other than on the isolated rocky hills and ridges which rise above the plains to a maximum elevation of 1640 m (Kasigau). The Taita lowlands and the more westerly Kwale hinterland are floored by gneisses and crystalline limestones of the basement complex and the surface soils are predominantly red and sandy except for black cotton soils which may occur along the more significant drainage channels, such as the Bura and Mwatate. Drainage incision decreases from the foothills of the Taita Hills to the Kwale District boundary consonant with a decrease in rainfall and runoff. To the east, the bedrock changes to the younger sandstones, shales and siltstones of the Duruma Sandstone Series and the overlying soils are mainly grey-brown in colour and of silty texture. Relief and drainage incision now increases again eastwards concommittant with increase in rainfall. Valley floors and sides have relatively thick colluvial and soil cover with intermittent outcrops occurring on the watersheds of bare sandstone, shales and flagstones.

2.2 CLIMATE

The study area has a mean temperature of about 24 degrees C, varying from a mean maximum of 32 or 33 degrees in February or March to a mean minimum of about 17 or 18 in July.

The study area can best be described as semi-arid, having a rainfall varying from below 500 mm annually over much of the area to some 600 mm in the extreme south-east and north-west. Rainfall in the locality of Kilibasi and Kasigau Hills is higher at perhaps 700 mm, but these areas of higher rainfall are too small to be of great significance.

Figure 2 shows the location of the raingauges operated within the study area by the Kenya Meteorological Department (KMD), and data from some of these stations were obtained for the study. Unfortunately, there are few stations at the centre of the study area apart from station 9338018, Rukinga Kasigau. This station is at an elevation of 656 metres compared with an elevation of some 550 to 600 metres for the surrounding area. The mean annual rainfall of 683 mm may therefore not be typical of the surrounding area where rainfall is likely to be somewhat lower.

The gauge at Mackinnon Road may be more representative of that in the study area. The mean annual rainfall at this station, computed from the data collected at KMD, is 659 mm, which is significantly higher than the KMD

TABLE 1 Significant raingauges within the study area which are shown on Figure 2

Raingauge Number	Name of gauge	Lat (Degrees S and E)	Long	Start Year
9338001	Voi Met Station	3 24	38 34	1904
9338003	DC's Office, Wundanyi	3 24	38 24	1929
9338007	Maktau Railway Station	3 25	38 08	1935
9338008	Mwatati Murry Girls School	3 27	38 21	1937
9338012	Taita Sisal Estate Ltd	3 33	38 24	1948
9338018	Voi, Rukanga-Kasigau	3 50	38 38	1950
9338020	Maungu Railway Station	3 33	38 45	1962
9338022	Bachuma Range Research Stn	3 48	38 57	1966
9338024	Bachuma Park Gate, Tsavo	3 40	38 56	1969
9338029	Taita Ranch Co Ltd	3 47	38 52	1972
9338031	Mgange Chief's Office	3 24	38 19	1973
9339002	Mackinnon Road Railway Stn	3 44	39 03	1904
9339006	Samburu Railway Station	3 47	39 16	1929
9339023	Maji ya Chumvi Railway Stn	3 49	39 23	1949
9439001	Kwale Agriculture Dept	4 11	39 28	1908
9439004	Gazi Association Sugar Works	4 23	39 30	1912
9439014	Msamweni District Office	4 28	39 29	1935
9439015	Kinango Agrigultural Office	4 08	39 19	1936
9439027	Kwale, Mwangulu Chief's Off	4 25	39 07	1948
9439028	Kwale, Ndavaya	4 15	39 10	1948
9439031	Shimba Hills, Mrere No.1	4 13	39 25	1949
9439044	Gazi, Kikoneni Agricult Stn	4 28	39 17	1953
9439053	Mkongani Chief's Camp	4 17	39 16	1971
9439056	Lukore Primary School	4 23	39 19	1971
9439057	Puma Chief's Camp	4 06	39 14	1970
9439061	Kwale Forest Station	4 11	39 27	1976

map figure of 550 mm. This this is partly a reflection of the different periods of data utilised. The KMD map was based on data available in 1966, although the starting date of the analysis is not stated. Examination of the mean annual rainfall at Mackinnon Road over time shows that there has apparently been a reduction in raingauge catch over the years.

Mean Annual Rainfall Mackinnon Road Railway Station Over Time

Period	Mean Annual Rainfall (mm)	Comments
1926 - 1988	659	37 Years
1926 - 1936	939	11 Years
1937 - 1947	530	11 Years
1963 - 1972	651	9 Complete years
1973 - 1988	391	6 Complete years

Examination of the table above shows that recorded rainfall in the period 1926 to 1936 was very much higher than that observed subsequently. This pattern is not observed at other gauges for which data were collected and hence the early data at Mackinnon road must be considered to be suspect. A more realistic annual average rainfall for this gauge may therefore be 540 mm, derived from the period 1937 to date. This figure agrees closely with the KMD published maps of annual average rainfall and supports these maps. Data from other gauges examined also tend to support the maps, therefore rather than analysing all of the collected data in detail, the published KMD map of annual average rainfall was taken as the best indicator of average rainfall throughout the study area.

The average annual potential evaporation from open water, E_o, has been taken from an early report prepared by Woodhead for the KMD (Woodhead, 1968). These mapped values are believed to be sufficiently representative of areal evaporation for the present studies. The annual evaporative loss form reservoirs, which E_o represents, would thus vary from some 2200 mm near MacKinnon Road to 2000 mm along the Voi to Taveta Road. This means that reservoirs would require a considerable depth of water to provide a sustained source of water throughout the year. Given an annual rainfall of about 550 mm, the nett loss of water from any reservoir would be some 1.5 m annually.

The annual potential evapotranspiration loss from grass would be about 80% of the open water evaporation figure, thus it would vary from 1600 to 1760 mm over the study area. The potential evaporation loss of different vegetations would depend on the physiology of individual crop types, but would in general be slightly less than the grass figure for most seasonal crops.

2.3 DRAINAGE

The study area generally slopes towards the south-east and the drainage pattern flows down the dip slope of the Duruma Sandstone series towards the coast. Two main rivers flow from the Taita Hills into the northern end of the study area, the Mwatate and Bura, and these join together in a large swampy area at Mangeri. It seems that in general little flow from the two rivers gets further south than these swamps, and the belief is that there is little significant flow into the Mwabeja and Chenze ranches of runoff originating in the Taita Hills. A poorly defined channel enters the Mwabeja ranch from the north-west through Wushumbu and Dawida ranches, but this channel appears primarily to drain a local catchment to the west and south of Kasigau Hill. There may be some flow into this drainage system from the Mwatate and Bura system in extremely wet years, but in general, any flow in the southern drainage system of the Mwatate will be locally generated.

The drainage pattern on the basement complex forms gently incised valleys with heavy, grey to black clay soils along much of the valley bottom. These poorly drained soils may provide suitable material for valley tank construction, but storages created will tend to be small as valleys are only shallowly incised.

On the Taru Grits, because of the geology, the valleys are hardly discernable and few, if any, dam sites are likely to exist. Local runoff may be high however, and there may be scope for development of rock catchments such as that at Kilibasi.

The Maji Ya Chumvi beds have eroded more than the Taru Grit series and valleys are somewhat more pronounced, though without being ideal for surface reservoirs. The drainage pattern shows that there are more streams on this rock than on the Basement complex or the Taru Grit series, but this is partly a reflection of the increasing rainfall towards the south-east.

2.3.1 Surface Runoff

There are no reliable long term flow records on any river in, or close to the study area. Therefore, assessing the reliable availability of surface water runoff is difficult. The two main rivers flowing from the north west, the Bura and Mwatate have some historic spot flow gaugings, but these are of very limited value. These were tabulated by Ward Ashcroft and Parkman (1983). The gaugings all seem to have been made in the upper reaches of the rivers close to the Taita Hills, and are therefore of limited use to the present study. The gaugings vary from less than one litre per second in June 1934 to 670 l/sec in April 1976, but the median flow is only 29 l/sec.

The Bura river has had relatively frequent current meter gaugings at a site in the Taita Hills (Grid Ref: 244 201) since December 1976 as part of the investigation into improved water supplies to the Mwatate town area. The average long term flow at this site has been just under 100 l/sec, with maximum flows of around 200 l/sec in April to June.

The river leaving the Taita Hills are normally perennial having flow all year round, although some periods of zero flow have been recorded, and these rivers potentially offer a reliable source of surface water for development. Unfortunately for the present studies, there are plans to utilise the bulk of this water locally in the Taita foothills region. Further discussion of this option will follow. In addition, the flows from the Taita Hills rapidly vanish as the rivers flow over the lowlands, partly through seepage into the underlying alluvium and partly through evaporation.

Estimates of annual runoff for all of Kenya computed by TAMS in their 1979 National Water Master Plan and were shown in Figure 3.6 of that report. These estimates were derived using a conceptual mathematical model which was calibrated against gauged catchments throughout the country. However, these gauged catchments were almost without exception in the wetter parts of Kenya and results may not therefore be truly representative of runoff from the more arid zones such as the current study area.

For the area of interest, the mean annual runoff is given by TAMS as 20 mm around the Taita foothills and Taveta to perhaps 15 mm over most of the study area. This does not seem unreasonable, although the figure may be slightly optimistic. For example, in Botswana which has a similar annual rainfall, but has only one rainy season, the average annual observed runoff is typically only 7 to 10 mm. It would seem reasonable to assume an annual runoff of 5 to 10 mm for the majority of the study area to be conservative. This represents a significant annual resource, although a high inter-year variability of both rainfall and runoff might mean that dams would not receive water in all years. In addition, because of the high spatial variability of the convective rainfall cells, it is possible that within a small area some dams might fill whilst others would receive little or no runoff in any rainy season.

Given an average annual runoff of 10 mm, a catchment area of 10 km^2 would generate a runoff of 100,00 m^3 (22 million gallons). The full capacity of Lukakani dam in comparison is 13 million gallons. Thus, given adequate storage sites, it should be possible to fill moderately large dams throughout the study area. The only problem is that few, if any, such storage sites exist naturally within the area. It may be possible to enlarge such potential sites as there are using earth moving equipment, but costing such engineering works is beyond the scope of the present studies. However, if earthmoving were undertaken by a commercial contractor, costs of KSh 150-200 per cubic metre have been quoted by a major firm of consulting engineers in Nairobi (Sir Alexander Gibb and Partners, (Africa), personal communication, 1990).

2.4 HYDROGEOLOGY AND GROUNDWATER RESOURCES

Aquifers occur in crystalline basement rocks and the Duruma Sandstone Series and to a more limited extent in valley alluvium and recent surface limestones. All existing records in the Ministry of Water's archives (Appendix 1) relate to boreholes drilled in the two main aquifers. There has been almost no recent drilling (post-1980) of the basement aquifers in the study area and the few reports which discuss the groundwater occurrence (Klassen. 1974, and MOWD, 1977) predate this time. There have been more recent studies, including some exploratory development, in the Kwale hinterland (Norconsult, 1986 and

Groundwater Survey (Kenya) Ltd, 1990), although these projects and studies have been mainly concerned with the more eastern part of the Kwale hinterland, largely outside the area of specific interest for this report.

2.4.1 Aquifers in Basement Rocks

Basement rocks underlie the Taita lowlands and western Kwale hinterland with outcrops mainly apparent on scattered inselbergs and low ridges. The eastern boundary is known to be a faulted junction with the Duruma Sandstone Series, although it is generally obscured by overlying soils and recent sediments. Basement aquifers occur either wholly within the residual weathered overburden (regolith) or also within the fractured bedrock. The regolith aquifer has typically low permeability and high storage and is usually developed by dug wells or shallow boreholes. The fractured bedrock aquifer has low storage but may have high transmissivity. A sustained yield from a borehole in a bedrock aquifer is only feasible if the latter can interact with sufficient storage contained either within saturated regolith or an overlying alluvial aquifer. The understanding of basement aquifer hydraulics and the interaction of storage and recharge is essential to successful development.

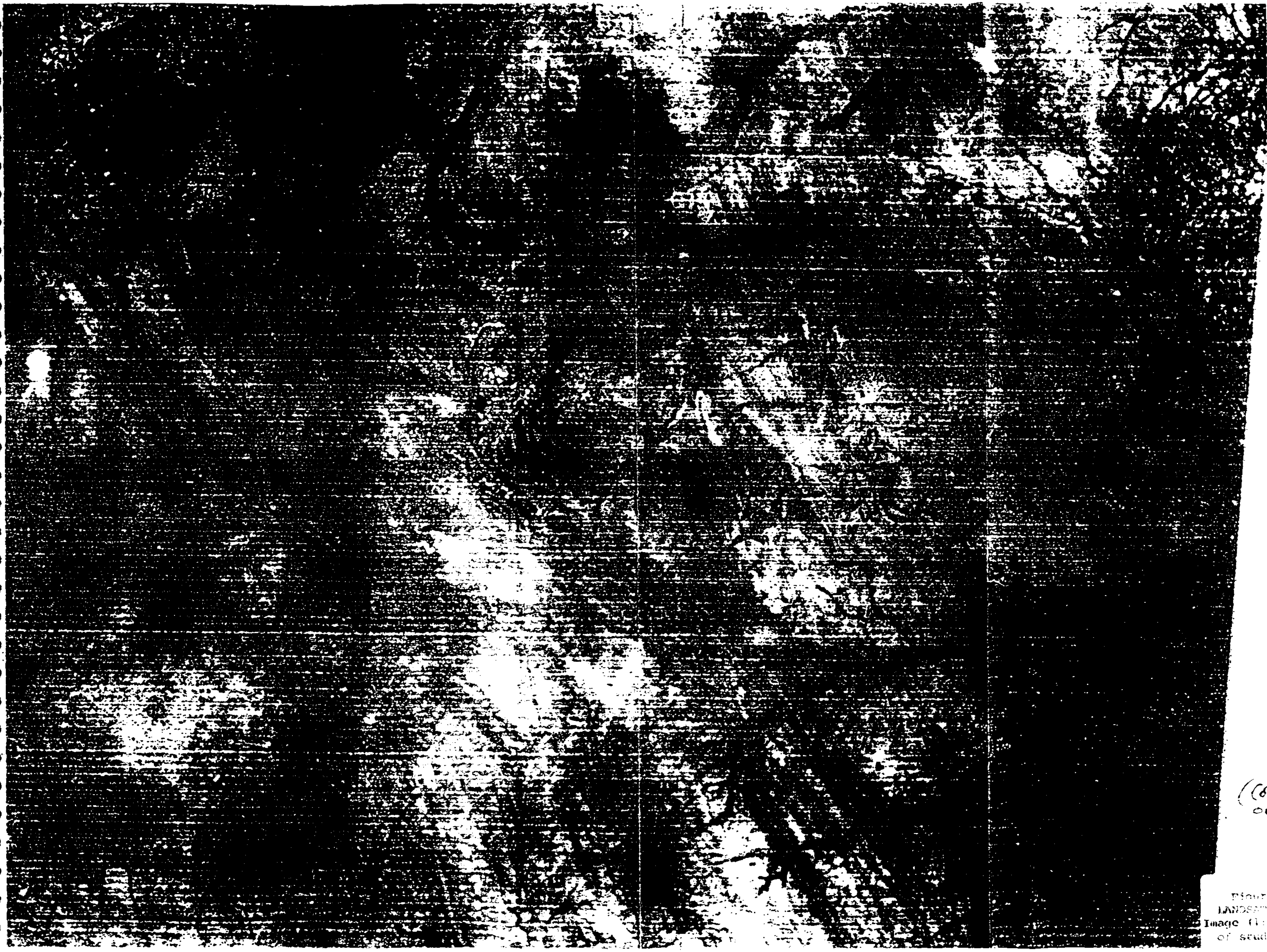
Direct recharge from rainfall to the basement aquifers in this area is likely to be small to negligible with mean annual amounts totalling 550 mm or less. Recharge is likely to occur only following runoff. There is some confirmatory evidence for this in that successful boreholes have been drilled in the Bura and Mwatate valleys close to the stream bed but boreholes drilled at short distances (a few km) to the side have been dry. Runoff in these valleys has been reported on by direct observation although only a handful of measurements have been made. The duration of runoff is known to decrease away from the Taita hills as, for example, in the Bura valley at the site of the most southerly successful borehole (3783) where up to six month duration of runoff is said to occur in most years, as compared with perennial flow near Bh 505 to the north.

Indications of runoff can also be obtained from multispectral satellite imagery (MSS) as evidenced by transpiring vegetation along the banks of the stream. A dry season (June) image of the study area enclosed with this report, Figure 3, clearly indicates that significant runoff has occurred in the Bura and Mwatate rivers to some 25 km south of the Taita hills. There is also some indication of additional runoff to join the Mwatate river from the Kasigau hill.

Thirty-eight boreholes have been drilled into basement rocks in the area of interest. The summary data abstracted from MOWD records are shown in Appendix 1 and some collated statistics are set out below.

(i) Water Quality

Total Bh	Dry/low yields (<6 l/min)	No data	Good	Potable	Saline
38	14		14		



(Coloured original in Archive)

Figure
LANDSAT MSS
Image (1:250,000)
of study area

(ii) Yields of successful boreholes (>6 l/min)

Total Bh	Mean	Median	Standard Deviation	Range
22	123	113	110	6-453

(iii) Rest Water Levels (metres below ground level)

Total Bh	Mean	Median	Standard Deviation	Range
24	20		14	2-49

Some explanation is required on the water quality codings. Groundwater from boreholes with these low yields will be mainly of consideration for domestic supply purposes and the codings are applied in that particular context. The World Health Organisations provides guidelines for drinking water quality but actual standards are based on prevailing environmental, socio-economic and cultural conditions. Temporary standards are sometimes set, such as the current standards in Tanzania, which identify the maximum permissible limits whilst still using the WHO guidelines as the maximum desirable limits. The MOWD data records for the majority of the older boreholes contain little geochemical data but mainly a general quality description - good, fair etc. Some analyses were carried out on selected boreholes by Norconsult (1986) in the Kwale hinterland studies and by use of these data and some MOWD descriptions, the following codings were arrived at and have been used in the Annex 1 and on the accompanying map.

Quality Codings (this report)	Total Dissolved Solids (mg/l)
Good (G)	0 - 1400
Potable (P)	1400 - 2450
Saline (S)	> 2450

A selection of a few key constituents are listed below along with the WHO guideline limits and the Tanzanian Government temporary standards limits. Although no geochemical analyses are available for the groundwaters of the basement aquifers in this area, the stated water quality codings are likely to be well within the maximum permissible limits and in most cases probably within the WHO guidelines.

Constituent	Unit	WHO Guide	Temporary Standards (maximum limits)
Flouride	mg/l	1.5	8.0
Nitrate	mg/l (N)	10.0	100.0
Chloride	mg/l	250.0	800.0
Hardness	mg/l ($CaCo_3$)	500.0	600.0
Iron	mg/l	0.03	5.0
pH		6.5/8.5	6.0/9.5
TDS	mg/l	1000.0	3000.0
Sulphate	mg/l	400	600.0

The 14 dry boreholes in basement aquifers are mainly concentrated in the Mackinnon Road and central Kenya Triangle areas. These are areas of low rainfall and without significant external runoff. The yields of the 22 successful boreholes are surprisingly high for boreholes in basement aquifers since the records mainly show water strikes in the weathered and fractured bedrock and rest water levels in the former. Most of the boreholes are sited along existing valley lines which overlie buried older channels with alluvial deposits and it is possible that the aquifer is partly contained within high permeability alluvial sediments. The boreholes are mainly sited at the perimeter of the marsh lands overlying black cotton soils with rest water levels some 10 to 40 metres below ground level which testify to the confining nature of these soils. Rest water levels below ground level deepen southwards and quality also tends to deteriorate in the same direction which indicates a reduction of recharge, corresponding with the observed reduction in runoff. The feature also suggests that the greater part of the runoff is derived from the Taita Hills which will allow a more accurate calculation of resources.

The groundwater resources of the basement aquifers in the Taita-Kilibasi area cannot be accurately estimated. On the assumption that recharge is mainly derived from runoff, runoff data from the Taita and Kasigau Hills would provide a figure of maximum possible recharge which would need to be refined by information on well water level changes, aquifer throughflow rates and aquifer geometry. However the very limited available data preclude detailed analysis at the present time. The probability of recharge elsewhere from runoff might be tentatively assessed from wet season satellite imagery with on site confirmation by geophysical surveys and drilling. Present indications of the likelihood do not give grounds for much optimism. There is however scope for induced recharge of the undoubted surplus of runoff in the main drainage lines from the Taita and Kasigau Hills by means of check dams and local stripping of cotton soils to permit infiltration. Geophysical surveys and imagery/air photographs could assist siting of recharge areas. The main drainage lines are underlain by high permeability sands and gravels of old alluvial channels and the deep water levels indicate an ample potential water storage space. Induced recharge would have advantages over surface dams in precluding evaporation but with a subsequent pumping requirement.

A key approach in any groundwater resource assessment is a study of existing production boreholes with time. The majority (20) of the successful boreholes are sited in the Upper Bura and Mwatate valleys. As far as could be ascertained during the short site visit, only four are currently operating and according to the pump attendants, no seasonal or longer term variations in yield or quality have been noticed. Well 505 in the Bura valley was drilled in 1945 and deepened in 1965 when a significant lowering of the water level and reduction in yield as compared with the original water level and test yield was recorded. The condition might be attributed to abstraction exceeding recharge but a more precise evaluation would be needed to confirm this supposition.

2.4.2 Aquifers in the Duruma Sandstone Series

The Series is composed of sediments of lacustrine, fluviatile, deltaic and shallow marine origins which were deposited during a period of alternating wet and dry climates. Some interbedded evaporites occur sporadically and account for the generally poor quality of the groundwater. The regional dip of the series is 5-10 degrees to the ESE and the contact with the older basement rocks to the west is faulted. Gentle folding has resulted in the occurrence of shallow anticlinal and synclinal structures. Both faults and folds are likely to have some influence on groundwater occurrence.

The five stratigraphic subdivisions of the Duruma Sandstone Series are listed below and the boundaries, other than between the Upper and Lower Taru Grits, are shown on the borehole location map.

Duruma Sandstone Series

Unit	**Description**
Lower Taru Grits	Massive, hard but locally well-jointed arkosic sandstones, sandy shales and conglomerates.
Upper Taru Grits	Yellow-brown sandstones and dark shales.
Lower Maji ya Chumvi	Soft shales and sandy shales.
Upper Maji ya Chumvi	Shales, siltstones and sandstones.
Mariakani Sandstones	Sandstones, siltstones and some shales.

In relation to groundwater quality, the Lower Taru Grits, the Upper Maji ya Chumvi shales and Mariakani sandstones would be anticipated to have better potential. But in all cases, older and more deeply circulating groundwater is likely to be saline and this is apparent from an examination of the borehole records. Drilling depths below 80 m or below 55 m, if no previous water strike has occurred, have a high probability of saline water (Groundwater Survey (Kenya) Ltd, 1990).

The Groundwater Survey report includes some statistical analysis of borehole data, either on the entire Duruma Sandstone sequence of the Kwale hinterland or on main lithological subdivisions. Regression plots involving depths, yields, water quality, water strikes show a wide scatter of points from which only broad conclusions can be drawn. The inherent difficulty of the approach lies in the multiple nature of the aquifers and perhaps more importantly in the significant variations in annual rainfall which occur from west to east across the hinterland. For this reason the statistics used in this report relate to the individual members of the series which because their outcrops are subparallel to the main annual rainfall isohyets are more likely to have a consistent rainfall occurrence.

The plots of water quality shown on the borehole map are constrained by a lack of geochemical data. Comparisons of MOWD qualitative ratings with the few analyses available indicate that the former tend to be overly optimistic and for this reason, none of the borehole waters in the Duruma Sandstone Series are shown to occur in the best quality category. Four analyses of better quality water are listed below and it is evident that even these waters exceed maximum permissible limits for either chloride, hardness or sulphate, even though within the limit for total dissolved solids. Variations of water quality with depth are also known to occur and in most cases the shallow water tends to be fresher. This is to be expected and probably correlates with younger water.

Borehole Number	TDS (mg/l)	Cl	pH	Hardness	Sulphate	Flouride	Iron
6505 (26m)	1650	500	7.9	950	850	1.65	
6602	2200	760	7.5	1940	636	0.5	2.6
6530	1920	830	8.0	868	167	3.2	2.7
6604	2280	1000	?	1120	?	1.1	1.6

Borehole yields in the Duruma Sandstone Series are relatively high and it is clear that the main constraint is chemical quality. With rainfall in excess of 700 mm, substantial recharge through sandy soils is feasible but potential groundwater resources will depend on the availability of storage and on a significant throughflow at the more shallow levels. High fracture permeability along fault zones in association with a positive hydraulic gradient into drainage lines will assist the latter condition; sufficient storage will not be available in the fissured bedrock but will need to be available either within the deeply weathered near-surface horizons (as in crystalline basement aquifers) or within saturated alluvial sequences in hydraulic continuity with the main aquifer. Exploration should attempt to identify these favourable 'combinations of circumstances', an approach which has clearly not been attempted in the past. Base flow data or durations of valley evapotranspirative discharge (from MSS imagery) would assist in the assessment of groundwater throughflow and the chemistry of baseflow would also be helpful in this respect. There might even be vegetation correlations with salinity. Anticlinal structures would promote throughflow and synclinal structures assist storage but with more probable increase of dissolved solids content. Fault zones, if steeply dipping, are best identified by electromagnetic survey techniques. The resistivity sounding techniques used to date are more appropriate for horizontally layered features but could help to identify shallow horizons with fresher water. Development techniques should favour shallow boreholes and dug well/collector wells; the latter have particular applicability for skimming of fresh water overlying saline water. The scope for induced recharge is less clear but would become more apparent with improved data on aquifer occurrence and surface water runoff and water quality, both in space and time.

2.4.2.1 Taru Grits Aquifer (Kt)

Some 24 boreholes have been drilled into the Taru Grits in the study area and selected statistical data are set out below.

(i) Quality

No	Dry	Potable	Saline	Unknown
24	8	4	11	

(ii) Rest Water Level (metres below ground level)

No	Mean	Median	Standard Deviation	Range
17	24	19	21	3-72

(iii) Yield (l/min)

No	Mean	Median	Standard Deviation	Range
	95	30	99	7-226

There are high proportions of dry and of saline boreholes but mean yields of the 7 boreholes with test data are quite high. The borehole locations are quite widely distributed. As far as can be ascertained, siting methods concentrated on identifying fault zones by resistivity soundings and probably without much consideration of recharge and throughflow conditions. The basement boundary is an obvious location for fracture occurrence but the two latter conditions will be more critical since rainfall is lower to the west. No information is available on the longer term performance of the boreholes which have been equipped with pumps.

2.4.2.2 *Lower Maji ya Chumvi Aquifer (Kc')*

(i) Water Quality

No	Dry	Potable	Saline
16	•		8

(ii) Rest Water Level (metres below ground level)

No	Mean	Median	Standard Deviation	Range
14	13	9	13	4.53

(iii) Yield (l/min)

No	Mean	Median	Standard Deviation	Range
8	101	58	104	5-307

Boreholes in the Maji ya Chumvi aquifer include only one dry occurrence and approximately equal numbers of potable and saline boreholes. The results appear somewhat surprising in comparison with the more sandy Taru Grits aquifer and may reflect the higher rainfall. The shallower rest water levels appear to confirm this indication. The behaviour with time of those boreholes fitted with pumps will form a critical assessment of potential resources but no information is available in any of the reports consulted or could be obtained during the short duration visit. The same comments on conditions favouring resource occurrence apply to this aquifer as to the Taru Grits aquifer.

2.4.2.3 *Upper Maji ya Chumvi aquifer (Kc") and the Mariakani aquifer (Km)*

There are insufficient numbers of boreholes in these aquifers in the study area for any considered assessment to be made and in any case their outcrops' occurrence are largely outside the area of main interest. The few boreholes which have been drilled are mainly with high yields and with potable water quality.

To summarise:the aquifers of main interest occur within the Taru Grits and Lower Maji ya Chumvi Shales. Development of the former has given disappointing results but appears more favourable in the latter. Resources cannot be estimated with any degree of accuracy and clearly conditions for favourable occurrence are very localised. In the right circumstances, yields of potable water of between 1-2 litres a second can be obtained. More detailed studies are needed, aimed at a better understanding of the conditions which favour recharge, rapid throughflow and the development of sufficient localised storage for adequate abstraction and a range of modern techniques should be applied to assist identification, including imagery, various geophysical methods, hydrological (base flow) and hydrochemical analysis.

3. Water Supply Options

3.1 LOCAL SOURCES

Local water resources represent the cheapest option but are clearly limited in potential and are likely to be suitable only for domestic water supply, ranching requirements and perhaps some minor small-scale irrigation. Resources cannot yet be evaluated with the degree of accuracy needed for planning and development purposes, and significant studies are needed to reach this level of knowledge. The information is also needed to assess any likely significant shortfall in supply which will have to be obtained from external water sources where this is both feasible and economic.

3.1.1 Surface water

As discussed above local surface runoff can be expected to be spatially and temporally very variable yet should provide a useful potential resource. Given an average runoff of some 10 mm over much of the area centred on Kilibasi Hill, it may be possible to develop sufficient surface storage in the form of small dams and valley tanks to meet the water supply needs of a scattered, largely agricultural population. However, with the limited incision of river valleys into the underlying geology, there are no known significant potential dam sites within the study area. A more thorough aerial survey followed up by surveys on foot would be required to try and identify suitable potential sites within the area. Undoubtedly some small to moderate reservoirs could be developed throughout the study area and given a specialist, locally employed workforce with bulldozers, scrapers and possibly draglines, small dams could possibly be developed relatively cheaply.

However, a number of problems would arise from such a proposal. The first is that much of the surface runoff is high in dissolved solids and water is often brackish to sometimes saline. This is caused by leaching of evaporite deposits, particularly from the Taru grits, and lower Maji ya Chumvi rocks. The sedimentary rocks of the Duruma sandstones were deposited in a shallow marine environment and the erosion products from the older basement rocks were transported by wind and water south-eastwards into these marine or lake basins. Cycles of uplifting produced shallow lakes which dried out through evaporation leaving heavy bands of evaporites within the shales, siltstones and sandstones, (Classen, 1974). Because of the low rainfall and hence runoff throughout the study area, there has been little removal of these saline deposits in runoff, and the relatively infrequent major runoff events have been unable to wash much of the material to sea. Thus given a typical, small runoff event, material is washed from the soil surface into the stream channels where it would be accumulated and concentrated in any small reservoirs created.

The problem would be exacerbated by the high evaporative losses from any reservoir. Given a nett annual probable water loss of some 1500 mm from reservoirs, there would be a concentrating effect on solutes, leading to a gradual build up of saline deposits. Because of the high nett evaporative loss, unless reservoirs could be constructed to retain a sufficient depth of water, they would be likely to become dry during the year. As discussed previously, the natural topography would permit development of only shallow reservoirs which would not be ideal for over year storage of water. Ideally, a mean water depth of 2 to 3 metres would be required, with a significant proportion of the reservoir having a depth in excess of 3 metres in order to protect against evaporation and seepage losses. Attempts have been made in the past to suppress reservoir evaporation, either through the addition of a mono-molecular layer of a waxy oil on the water surface or by the use of floating covers. Whilst these have reduced evaporation under some circumstances, the cost of applying and maintaining the suppressant (where the layer is broken down by wind action and needs to be re-applied), has never proved economically viable. Unless the unit sale price of water is set at a very high level, the costs of water saving cannot be recovered and hence for the present studies the option is not worth detailed consideration.

Thus to conclude, it should be possible to develop small valley tank storages and possibly to find suitable locations for small dams within the river valleys which might provide water supplies for cattle watering, and possibly for small scale irrigation of food crops for homesteads. There would not however by sufficient water for commercial irrigation, not because of any lack of the basic resource, runoff, but because inadequate storage sites are believed to exist. It would not be feasible to construct artificial storages of sufficient capcity to sustain commercial irrigation because of the high costs fo such an undertaking.

Other potential minor surface water sources of supply are discussed in Section 3.1.3 where rock catchments, roof catchments and rainwater harvesting are considered.

3.1.2 Groundwater

The Taita lowlands and a marginal strip of the western Kwale hinterland is underlain by crystalline basement rocks (see Figure 1.). Since annual rainfall in this area may only marginally exceed 500 mm, direct recharge to underlying porous rocks is likely to be negligible and groundwater resource occurrence will depend on infiltrated surface runoff. The most significant drainage lines are the Bura and the Mwatate in the vicinity of which the majority of existing successful boreholes have been drilled and which derive runoff largely from rainfall on the Taita Hills and to a minor extent from Kasigau Hill also. Observed runoff in these valleys (confirmed by a dry season satellite image) appears to extend some 25 km to the south of the Taita Hills but the amounts cannot be quantified since very few flow gaugings have been carried out. The same satellite image indicates minor increments to the lower Mwatate from Kasigau which reaches the Kwale District boundary and this supposition also corresponds with observations of local residents at Kilibasi. Wet season imagery might also help to identify other areas of significant runoff although these are unlikely to be comparable to the two main drainage lines referred to. Additional development of groundwater is likely to concentrate first on the Mwatate and Bura drainage lines and studies on their existing well fields and boreholes are needed to assess current abstractions and any trends which might be indicative of over-development. Flow gauging is also to be recommended and will give information on the maximum potential which may exist both for surface and underground storage. If further development seems feasible, exploration should include geophysical surveys aimed at identifying fresh water occurrence, fracture zones in the bedrock, regolith thickness and the lithology and geometry of any buried alluvial channels. With indications of surplus runoff, consideration of induced recharge should also be included leading perhaps to pilot projects. The same procedures should be followed in any other potentially favourable areas which have been indicated by wet season satellite imagery. In areas devoid of significant drainage lines, groundwater resource potential is likely to be negligible and alternative sources of supply should be sought.

The Kwale hinterland is largely underlain by the Duruma Sandstone Series and in the area of present main interest these include principally the Taru Grits and the Lower Maji ya Chumvi Shales. Rainfall increases progressively eastwards from 500 mm/annum in the vicinity of Kilibasi Hill near the Kwale District boundary. Recharge potential also correspondingly increases eastwards but the major constraints are either a lack of permeable zones, most notably in the Taru Grits and reflected by a large number of dry boreholes, or high salinity which is common in both the Taru Grits and the Maji ya Chumvi Shales. In the drier areas, emphasis will need to be placed on locations where recharge from runoff is more probable and such areas are likely to occur on the outcrops of the Taru Grits. Permeable zones and fresher water may be identifiable by geophysical survey but consideration will also need to be given to the occurrence of adequate storage which may be found in overlying alluvial formations or the more weathered upper levels of the bedrock. Farther east the problem is more one of salinity and emphasis is needed on identifying fresh groundwater which is more likely to occur at shallow levels and in association with anticlinal structures or fault zones near drainage lines, both of which will promote rapid throughflow. With higher rainfall, fresher groundwater may occur on watershed areas but may be difficult to abstract if the zone is thin. Here also, as in the basement aquifers, the resources cannot yet be evaluated with the degree of accuracy required for planning and development purposes. Studies are needed to identify the more appropriate combination of circumstances which result in the occurrence of fresh water in sufficient quantities to permit abstraction. The studies should include surface hydrological and hydrochemical surveys (which will be also needed to assess the surface water resources) and will also benefit from the use of more sophisticated techniques such as satallite imagery analysis and geophysical/geochemical methodology.

Because of the overall constraints caused by low rainfall/little recharge or by the occurrence of interbedded evaporites in the bedrock resulting in saline groundwater, water supply should aim to develop the cheapest and most appropriate of a range of possible options which are discussed elsewhere in this report. In view of the common occurrence of high yielding boreholes with brackish to moderately saline water, desalination techniques may be worth considering to obtain a supply of high quality water for drinking purposes only. The supply might be mixed with poorer quality borehole water and the latter used exclusively for all other domestic purposes. Groundwater of 'potable' grade should be normally adequate for all ranching purposes. Actual drinking water requirements are probably less than 3 litres per capita per day. The cheapest systems for small production systems (less than 200 cubic metres per day) include solar distillation and reverse osmosis and total operating costs (capital, operating maintenance, discounted replacement etc) are in a general range of 5-7 US$ per cubic metre. There are of course economies of scale for larger units down to perhaps 50 cents a cubic metre for a production of 20,000 cubic metre per day.

3.1.3 Other Minor Sources

Although rainfall throughout the study area is limited, it could usefully be captured in various ways to meet domestic and some agricultural requirements. This could be achieved by means of constructing concrete retaining walls on some of the extensive outcrops of Taru Grits to retain rainfall and local runoff in rock catchment dams. One such rock catchment was inspected near Kilibasi village.

Another means of capturing rainfall for domestic use would be through roof catchments. Given that some large institutional buildings such as schools, shops and possibly small factories/processing plants may be constructed, if these are roofed with corrugated iron or similar impervious material, the runoff could be collected in storage tanks for water supply. Such schemes are increasingly used throughout Africa and other developing countries.

Finally, consideration could be given to rainwater harvesting for agricultural purposes. This is commonly achieved by construction of rock and clay lined bunds along contours to prevent rapid runoff of rainfall. By trapping runoff in a series of shallow pools behind the bunds, infiltration is encouraged and rainfall is retained in the soil upon which rain-fed crops can be grown. the system is cheap to develop and may be carried out using local labour and materials. Such as approach could enable local people to grow sufficient vegetables during the two rainy seasons to meet their needs. If this approach were combined with valley tanks and small dams, it is likely that sufficient water could be retained during the rainy seasons to meet such small scale irrigation needs. However, as stated previously, it is felt that surface water resources and potential storage facilities are not adequate for large scale, commercial irrigation unless a very high value cash crop were to be grown. It is uncertain what types of crops would be suitable and potential markets would have to be considered before such schemes could be planned or developed.

3.2 TAVETA SOURCES

There is water of excellent quality available in the Taveta area including sources in Lake Chala, the Lumi river and associated tributaries, various springs and aquifers in high permeability volcanic rocks. Recharge is derived from rainfall, runoff and infiltration on Mt Kilimanjaro. Provided the immediate catchments are protected, direct entrapment of spring flows or abstraction of groundwater would have the advantage of low to negligible treatment costs for domestic supply usage. Water quality also appears excellent for irrigation although as yet no determinations have been made of possible toxic constituents such as boron.

These sources can be considered for local usage or for export elsewhere. Preliminary decisions require information on cost sensitivity to various engineering factors to include pipeline diameters and materials, feasibility of gravity flow and alternative/additional pumping costs, and distances to points of use. Cost-benefit analysis would need to contrast local usage against export. A proposal was put forward in 1976 (Gauff K G, Con. Eng) to transport 138 l/sec from the Njukini and Sainte springs in the upper Lumi catchment to supply a number of townships (Voi, Mwatate, Maklen, Bura) and 23 ranches in the lowland areas to the north and south of the Taita Hills. The scheme was not implemented due to cost considerations and the more recent Taita-Taveta Development Plan (1989-1993) commented that the costs would appear even more unfavourable at the present time. The map distances to Kilibasi hill from the major Taveta sources are in the range 150 to 180 km along routes involving least elevation and reasonably direct. Sources at or in the vicinity of Lake Chala and the northern Lumi springs could supply the Kilibasi area mainly by gravity; from the Njoro Kubwa springs, some pumping would be necessary. For a one cumec supply, distances and required pipeline diameter would be comparable to the Mombasa Mzima pipeline with added costs such as pumped abstraction from Lake Chala or the costs of construction of an adit, or pumping from the elevation of the Njoro Springs.

Detailed costings for a pipeline have not been prepared for this study. However, estimates of current Kenyan prices for steel, concrete and uPVC pipes have been obtained from Sir Alexander Gibb and Partners in Nairobi. For a 1.5 m diameter concrete pipe, roughly the diameter required to transmit 1.5 to 2 cumecs from the Taveta district to Kilibasi, the cost of pipe would be about KSh 4300 per metre. The cost of laying the pipe could be about the same cost. Thus the cost per kilometre of pipe line would be about KSh 9 million. Steel pipe would be more expensive, but would be more durable and involve less long term maintenance.

3.2.1 North Lumi Springs : 975 m; 0.6 cumec

This was the source area for the 1976 proposal referred to earlier and 0.6cumec was stated as the minimum flow of two main springs, Njukini and Sainte, based on recent records. In view of the modest offtake proposed, the recent flow records were probably adequate. If larger demands are envisaged, a more careful assessment of the springs' discharge rates with time would be necessary. In a recent study (1989) of the Lolturesh springs to the north of

Kilimanjaro, significant variations of yield with time were noted. By correlations with rainfall and projections back to 1918, the 80% exceedence of flow was shown to be less than half the maximum flow rates. The period of recent records must therefore be correlated with the same period of Kilimanjaro rainfall and longer term projections estimated. The Ziwana Sisal Estate takes approximately 0.57 cumec but these are derived from two dams on the Sainte and Njoro rivers and the exact dependence on the spring discharges is not known. To assess further potential, additional exploration of the area could be justified since it is known that there are various other minor springs and seepages. Abstractions could be increased by boreholes.

3.2.2 Lake Chala

The lake level is at about 842 m and the lowest section of the crater rim on the Kenyan side is c945 m. There would be environmental and technological constraints to abstraction from the lake but simple calculations on the associated aquifer which feeds Lake Chala and assuming uniform conditions suggest that an abstraction of 1.4 cumec may result in only a few metres drawdown (see fuller discussion in the Interim Report). However because flow in the Chala volcanic aquifer is essentially of fissure type and feeds widely separated spring outlets, such calculations are unlikely to have high accuracy and improvements would require a significant programme of test drilling and aquifer testing in the vicinity of the lake. An easier, cheaper and more certain approach would be to carry out a long term pumping test from the lake, carrying the discharge into the Lumi river. Eventual abstraction, either by direct pumping as in the test or by means of an adit which might allow gravity discharge, could then be considered. The nearest location at low elevation in the Lumi River at 823 m would intersect the lake at some 19 m below current water level. Lake water levels are known to have fluctuated over some 4 m since 1945. The length of the adit would be about 1 km and the diameter would depend on optimising the engineering factors relating to flow and hydraulic head. It should be noted here than any abstraction from Lake Chala is likely to reduce the flows in the springs to the south of Taveta but from some points of view, this might be regarded as beneficial since surplus flows exist.

3.2.3 Well Field to South of Lake Chala

Eight boreholes to the south of Taveta are completed in the same volcanic aquifer as Lake Chala and produced a mean yield on test of some 4.5 l/sec. These yields could be improved by larger diameter boreholes (or by a collector well) but since no data on pumping test drawdowns are available in the Ministry records, any projected increase cannot be accurately calculated. It is unlikely however that a yield higher than 10 l/sec could be produced from standard boreholes since the aquifer is relatively thin, which limits available drawdown. A well field to the south of Lake Chala could be constructed to intersect the same aquifer but borehole depths would need to be of the order of 75-150 m and perhaps up to 100 boreholes would be needed to obtain one cumec. Indicative borehole costs, if completed with a high quality screen and gravel pack, could be of the order of 12 000 to 18 000 US$. It may be noted at this juncture that an alternative use of Lake Chala's water would be for irrigation by gravity flow to land with good quality soil between Lake Chala and the Voi-Taveta road (MoWD Irrigation Section, 1983).

3.2.4 South Lumi Springs (Njoro Kubwa and associated springs) : 762 m; 6-10 cumecs.

There are three main groups of springs which discharge into the Lumi river to the south of the Voi-Taveta road. Combined flow is stated by MoWD Irrigation Section (1983, op.cit.) to be 9.9 cumecs but no information is available on discharge changes with time. Currently, there is only limited use of the spring flows for irrigation and sisal processing and the newly installed township supply but the MoWD report also noted that up to 6 cumecs could be used for low cost irrigation to the south of the Voi-Taveta road and the remainder used to irrigate land to the north of this road but pumping would be needed. Thus at the present time and in a short term context, there would appear to be no constraint to taking between 1-2 cumec for use outside the area. Indeed there could be short term advantages since the spring flows augment the seasonal flooding in the Taveta area. Pumping would be required for transfer to the Kilibasi area and in the longer term context the fluctuations of the spring discharges would need to be taken into account as well as comparative cost benefit analyses in relation to local usage.

3.2.5 Lake Jipe

The quality of Lake Jipe is reported to be poor but the electrical conductivity of samples from the northern end of the lake gave values of 1300 microsiemens at 25 degees C. (equivalent to dissolved solids content of 910 mg/l) and therefore fairly good. However the lake is at a level of about 700 m and substantial pumping would be needed for a supply to the Kilibasi area. The source offers no advantages over the other sources in the Taveta area.

3.3 TAITA HILLS

One possible source of water for the study area might be the rivers draining from the Taita Hills. It has been suggested earlier that runoff from the hills into the Bura and Mwatate rivers will only infrequently pass through the Mangeri Swamp. In general, flows from the hills will rapidly be lost through seepage and evaporation.

It may be feasible to construct storage dams within the Taita Hills to provide water to the study area, although it is known that current studies are looking at such a scheme to supply domestic water requirements to the Mwatate township area and the villages along the Voi to Taveta Road. The quantity of water to be developed by the proposed scheme (Ward, Ashcroft and Parkman, 1989), is relatively small at only 2000 m^3/day (0.44 million galls/day), which is designed to supply some 32000 people by the year 2007.

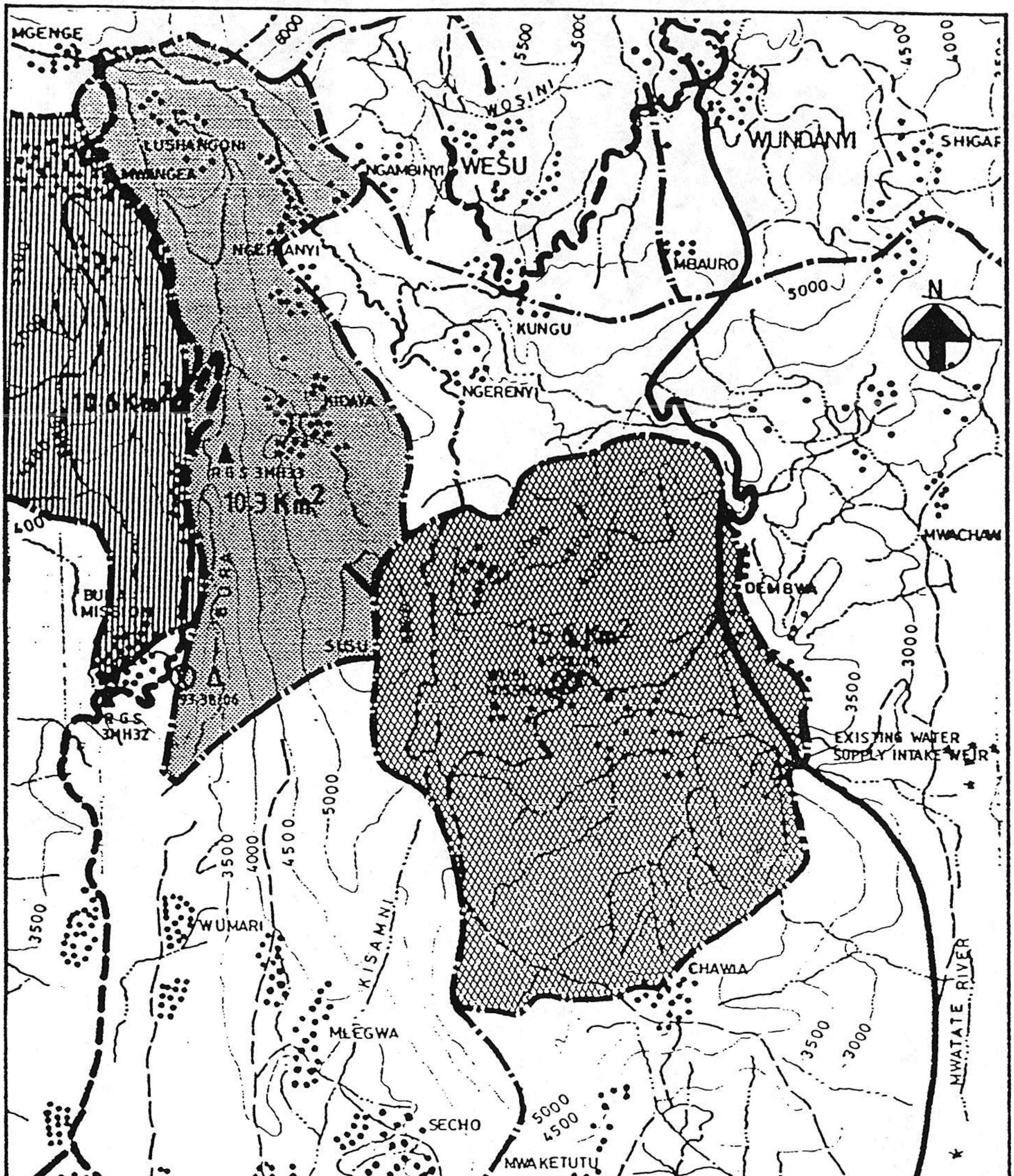
The proposed dam sites are high in the Taita hills and capture runoff from very small catchments, 15.6 km^2 on the Mwatate and only 10.3 km^2 on the Bura. The location of the proposed sites is shown on Figure 4, which is taken from the WAP report. The selected damsites are the best possible on geotechnical grounds in as much as the valleys widen significantly downstream and very much larger dams would be required to achieve only a relatively small additional yield. In order to increase the reservoir yields significantly either more than one catchment would have to be dammed or a large, expensive dam would be required further down the valley. This latter option may not be feasible due to agricultural development in the lower valley and because gravity supply to the study area may not be feasible. It is possible that better dam sites exist on the Voi river, which having a greater catchment area, has greater runoff. This possibility has not been studied in detail.

The cost of the proposed schemes on the Bura and Mwatate are 48 and 44 million KShs respectively, roughly half the cost being for dam construction, one fifth for construction of a water treatment plant and the remainder being for running costs, pipelines and so on. The cost of dam construction works out at about 170 KShs per cubic metre of earth moved, very similar to that suggested by Sir Alexander Gibb and Partners.

Further work would be required before other potential damsites in the Taita Hills could be identified should this be thought necessary. However, in view of the very high cost of constructing dams and the high costs of transporting water to the Kilibasi area, dam development in the Taita Hills does not seem to be a viable proposition.

3.4 MZIMA SPRINGS

The Mzima springs have water of comparable quality to the Taveta springs and Lake Chala and are at an elevation of about 914 m. Of the current discharge of 5 cumec, some 8% (0.4 cumec) is diverted into a 209 km pipeline to supply Mombasa but a second pipeline is planned to increase the offtake to 25% (1.25 cumec). However flow of the Mzima springs has fluctuated considerably in the 40 years since records commenced and at times has decreased to as low as 3 cumec. Care is therefore needed to balance the dry season offtake at Mzima against other demands for water downstream including the Tsavo park and the lower Athi river, including the Baricho intake. Other potential sources for Mombasa supply which which could reduce the dependence on the Mzima source could include 0.3 cumec from the Tiwi coastal aquifer to the immediate south of Mombasa (British Geological Survey/MoWD report, June 1986) and an unquantified but possibly substantial potential amount from the subsurface flow below the Baricho intake on the Athi river. Also, if the proposed dam on the Upper Athi river should be constructed, there would be major additional resources available at Baricho. Without such additional resources being made available for Mombasa, it would appear probable that no substantial offtake to the Kilibasi area from the second Mzima pipeline can be anticipated.



CLIENT	MINISTRY OF WATER DEVELOPMENT - REPUBLIC OF KENYA
SCHEME	MWATATE WATER SUPPLY PROJECT
TITLE	SKETCH MAP OF LOCAL RIVER CATCHMENT AREAS
[illegible]	Figure 4 [illegible] JUN, 1988

KEY
- RAINGAUGE
- RGS
- MISCELLANEOUS GAUGING SITE
- MWATATE CATCHMENT AREA
- BURA CATCHMENT AREA
- SANGA CATCHMENT

WAP

East Africa

4. Conclusions and Recommendations

4.1 SURFACE WATER RESOURCES

As stated previously, it seems that a number of small dams and valley tanks could probably be constructed throughout the study area to provide sources of water for livestock, and perhaps limited irrigation of food crops. It is not recommended that these sources also be used for domestic water supply because of the inevitable pollution of the reservoir by cattle. The existing dams within the area at Lukakani and Mblini and the various valley tanks are commonly used both for ranching and for human supply. there are inevitably health risks to the human consumers.

A better option would be to attempt to develop scattered groundwater supplies throughout the area suing boreholes and even hand dug wells (possibly combined with collector wells), to meet domestic water demands. Whilst many boreholes may have brackish to saline water, it should be possible to develop a sufficient number of groundwater sources of adequate quality throughout the area provided a scientific approach to borehole siting is adapted. The point is discussed further in the following section.

The main point to be emphasised, however, is that human and animal consumers should not share the same untreated surface water supply. The cost of treating the surface water source, or at least that portion of it used for human consumption, are probably high given the proposed scattered nature of both the dams or valley tanks and the largely agricultural population. Simple treatment using for example ultra-violet light may be an economic option if surface water supplies seem to be the only reliable source in any particular situation, but in general separate domestic water supplies should be developed.

Because of the very limited hydrological data within the study area, it has not been possible to make firm statements as the siting or sizing of dams within the study area. Nor is it possible to state with confidence that any dams constructed would definitely impound water through the entire year. However, it is our belief that if the storages are sufficiently large, water would be available all year round for say 9 years in 10. This of course begs the question "how large is sufficiently large?". The question is difficult to answer but the existing reservoirs may be used as analogues of potential damsites. The Lukakani and Mblini dams each store around 12 million gallons (approx 55,000 m^3) and are reported to contain water all year round. Such storages could be supplied by catchment areas or only some 10 km^2 given the suggested mean annual runoff of 10 mm, although from experience in other semi-arid regions, the coefficient of variation is likely to be 80 to 100%. Lukankani dam appears to be fed by a catchment area of about 40 to 50 km^2 (it is difficult to be precise without 1:50,000 scale maps or aerial photographs). the dam is reported to contain water all year round and to fill every year. The indirectly confirms that the assumed runoff of 10 mm is generally of the right order of magnitude, although given the probably coefficient of variation of 80 to 100%, the annual runoff for 2 years in three might be in the range of 1 or 2 mm to 20 mm.

Thus, a detailed field survey should be undertaken using serial photographs initially followed by overflying the area and finally survey on foot. If dam sites with sufficient apparent storage and mean depth can be identified, clearer development plans for the area could be prepared.

The potential dams will provide relatively small quantities of water for ranching and small scale irrigation of food crops only. It seems unlikely that sufficient storages exist to sustain significant commercial irrigation.

There remains the option of importing water to the area, either from the Taveta region or Lake Chala or from the Taita Hills, but the likely costs of such transfers are likely to be prohibitive. Very crude outline figures for such options have been given earlier for such schemes.

4.2 GROUNDWATER RESOURCES

4.2.1 Taita - Kwale Districts: local resources

Groundwater resources in the area of planned agricultural development have some potential for domestic supply and ranching and perhaps occasionally for small scale irrigation, but present information is insufficient for extensive planning and development.

Groundwater occurs mainly in aquifers in crystalline rocks and in the Duruma Sandstone Series and may also occur in shallow recent alluvial formations. Basement rocks underlie the Taita lowlands and the western margins of the Kwale hinterland. Rainfall is low, probably not exceeding 550 mm per annum, and aquifer occurrence is largely limited to those drainage lines in which recharge from runoff is occurring, notably drainage originating in the Taita hills and Kasigau. Whether other drainage lines carry sufficient runoff on occasions to generate a groundwater resource is not known. Water quality in the successful boreholes drilled to date is good to potable.

Resources in the basement aquifer, both probable and potential, can best be evaluated by runoff gauging but studies of satellite imagery at various seasons could provide qualitative and spatially semi-quantitative information. There is also likely to be some potential for induced recharge sine the aquifer's rest water levels are generally at some depth below the valley floors which are commonly sealed by black cotton soil cover.

Potential development will almost inevitably be restricted to the vicinity of the main drainage lines generating runoff and areas outside these environs will require transported water. Any surplus which can be piped from the valley aquifers will represent the cheapest option

The Duruma Sandstone Series outcrop over the Kwale Hinterland and with an annual rainfall in the range 500 to 800 mm annually, there is an obvious potential for recharge to underlying aquifers. Existing borehoes show that groundwater resources do exist over a large area of the hinterland but with significant local constraints on either borehole yields or groundwater quality.

Successful boreholes have a relatively high yield (several litres a second) but quality ranges from barely potable to saline. Dry boreholes are more common in the Taru Grits than in the Lower Maji ya Chumvi shales and the occurrence seems to be due to a failure to intersect permeable zones in the fractured aquifer systems. There must also be an uncertainty on sustained yields of the successful boreholes but no records appear to be available on their performance with time. The uncertainty resides in the limited porosities of normal fissured aquifers and the need in such cases to intersect hydraulically with zones of high storage which could be a very weathered overburden (as in basement aquifers) or saturated alluvial aquifers. Weathering tends to be less marked in rock formations of this type as minerals in sedimentary rocks are more stable geochemically. High salinity is due to the presence of interbedded evaporites and saline groundwater is almost inevitable in any borehole which intersects more deeply circulating groundwater. Statistics assembled by Groundwater Survey (Kenya) Ltd, 1990, demonstrate that boreholes in excess of 80 m deep or boreholes which do not strike water above 55 m are almost invariably saline. Exploration should therefore seek to intersect more rapidly moving and shallow circulating groundwater systems. These are more likely to occur in association with fault zones intersecting drainage lines with a positive hydraulic gradient. Since some runoff is also saline, local bank storage (i.e. recharge from runoff) can also be saline.

Studies are needed to evaluate the complex association of fresh and more saline groundwater. Resources of the fresh groundwater will not be easy to evaluate quantitatively because of this complex association but since recharge potential is quite high, if the conditions governing the occurrence of fresh water can be identified and prove to be widespread, there can be a corresponding optimism of resource occurrence.

4.2.1.1 Recommendations for Studies

Studies are required on both the basement and the Duruma Sandstone Series aquifers and on potential aquifer occurrence in alluvial formations. They should include inventory and other regional surveys leading to more site specific investigations including drilling.

Regional Surveys

(i) Well inventories which should evaluate the sites and groundwater occurrence in all previously drilled boreholes to include considerations of yield, water quality and water levels, both spatially and with time and in possible association with other hydrogeological and surface hydrological features. Studies should examine in particular detail, those boreholes giving higher yields and better quality water in order to identify the conditions which have given rise to such occurrences.

(ii) Runoff gauging on main drainage lines. Emphasis should be on flood runoff in the ephemeral streams which have potential for recharging basement aquifers. In the streams with more sustained flow on the Duruma Sandstone outcrops, baseflow will also have a particular significance since it will reflect groundwater recharge and groundwater quality.

(iii) Hydrochemical surveys of both ground and surface water in both space and time. Fluid conductivity logging in boreholes could help to identify significant variations of quality with depth and in particular, the occurrence of fresh groundwater. If it occurs at shallow levels, as anticipated, dug wells and collector wells represent a better abstraction option than deep boreholes.

(iv) Studies on satellite imagery (various types including MSS, TM and NOAA-Meteosat) at different seasons to assist in evaluating areal rainfall, runoff locations, groundwater discharge and structural features in bedrock geology.

Site Studies

(i) Site studies at more successful boreholes have been referred to earlier. Longer term pumping tests could also be carried out to evaluate the hydraulics of the aquifer systems and the occurrence of storage/specific yield in what are probably dual systems(fissures and porous medium).

(ii) Exploration and development studies using air photographs, geophysical surveys etc., leading to test drilling or dug well construction. Drilling programmes should aim to identify vertical changes in aquifer characteristics including water quality.

(iii) Pilot projects on induced recharge and collector wells.

4.2.2. Taveta District

Groundwater sources include springs, aquifers in volcanic rocks, and in a strict sense, Lake Chala. There is at present a surplus of resources since the existing springs and other groundwater discharges are used to only a small extent. The general sequence of investigations is envisaged as follows:

(i) Evaluation of costs of piping water (with any necessary pumping to provide elevation) from the various Taveta sources to the Kilibasi area. Cost comparisons with the socio-economic benefits of proposed usage. At first sight, it seems unlikely that it is economically feasible to transport water such distances for rural water supply development purposes.

(ii) If transportation costs are within acceptable limits, more investigations will be needed on the sources of supply, both to evaluate sustainability of supply (changes of spring discharge with time and correlations with rainfall; likely water level changes in Lake Chala which will also reflect rainfall changes) and the costs of site works (boreholes, adits, pumping costs etc). A pumping test on Lake Chala would be included in this part of the work programme.

(iii) Cost benefit comparisons of local usage of the Taveta water resources (mainly irrigation) against transportation and usage in the Kilibasi area.

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Appendix 1 Record of boreholes within the study area

1 BH No;	2 LAT S	3 LONG E	4 ELEV m	5 YEAR	6 TD m	7 SWL mbgl.	8 NO Hoz	9 RWL mbgl.	10 Q lpm	11 LITH	12 S m	13 WQ
KWALE DISTRICT												
178	344	3903	183	1954	110	110	1		150	B		S
189	346	3916	274	1942	122		0			kt		D
190	346	3917	290	1943	153	98	1	38	226	kt		S
191	344	3904	358	1943	100		0			B		D
206	345	3911	320	1942	107	96	5	38	40	kt		P
232	344	3906	338	1943	92	56	1	38	222	kt		?
656	344	3906	366	1948	122		0			kt/B		D
668	343	3901	396	1948	124	92	2	58	4	B		P/D
700	347	3916	259	1948	121	78	1	31	7	kt		S
763	350	3915	244	1948	12	8	1	3	140	kt		P
764	347	3919	228	1948	80	32	1	10	180	kc^{1}		S
766	409	3919	183	1948	94	43	1	34	423	km		?
767	350	3845	506	1948	74	38	1	38	34	B		P
830	401	3920	244	1949	118	20	1	38	204	kc^{11}		P
856	415	3910	137	1949	109	16	1	10	307	kc^{1}		P
877	406	3914	216		183	71	1	22	58	kc^{1}		P
1107	410	3916	220	1959	137	110	2	57	113	kc^{11}		?
1108	354	3920	198	1959	119	5	1	4	62	kc^{1}		S
1109	342	3916	274	1950	96	61	2	10	314	kt		S
1165	410	3914	244	1950	99	70	3	33	176	kc^{11}		P
1727	401	3910	246	1952	168	62	1	62	11	kt		S
1763	402	3912	229	1952	129	103	2	53	42	kc^{1}		S
1982	406	3910	249	1953	122	92	4	2	7	kc^{1}	61.0	P
2040	358	3905	282	1953	134	134	2	4	22	kt	81.0	S
2200	344	3902	366	1954	122	43	1	23	4	B		S/D
2210	342	3003	372	1954	117	46	2	25	6	B		S
2408	359	3914	183	1955	147	142	2	24	151	kc^{1}	32.0	P
2649	408	3900	381	1957	89		0		0	kt		D
2791	430	3916	23	1958	30	5	1	[illegible]	76	km		?
3398	410	3840	552	1966	74		0			B		D
3414	411	3840	533	1966	122		0			B		D
3415	410	3842	594	1966	38	17	1		2	B		P/D
4167	424	3919	30	1975	177	126	2	13	23	km	130	P
6504	461	3908	300	1985	67	12	2	4		kc^{1}		S
6503												S
6505	409	3905	300	1985	77	24	2	24		kt		P
6506	358	3907	300	1985	120	96	1	27		kt		S
6507	304	3908	300	1985	70	33	1	4		kt		P
6508	351	3908	300	1985	58	32	1	5		kt		S
6509	404	3905	300	1985	70				D	kt		D
6510	354	3904	500	1985	102	53	2	32		kt		S
6512	403	3908	300	1985	70				D	kt		D
6513	359	3900	300	1985	77			72		kt		S

Appendix 1 Continued

1 BH No;	2 LAT S	3 LONG E	4 ELEV m	5 YEAR	6 TD m	7 SWL mbgl.	8 NO Hoz	9 RWL mbgl.	10 Q lpm	11 LITH	12 S m	13 WQ
KWALE DISTRICT CONTINUED												
6514	400	3906	300	1985	40	25	2	3		kt		S
6527	400	3901	300	1985	102	70	1	10		kt		D
6528	359	3911	300	1985	34					kt		S
6529	358	3901	300	1985	70	20	1	19		kt		S
6530	403	3910	300	1985	70	44	1	4		kc[1]		?
6531	402	3909	300	1985	52	35	1	6		kt		S
6532	405	3913	300	1985	70				D	kc[1]		D
6533	412	3901	500	1985	70	30	1		D	kt		D
6534	413	3904	500	1985	64	12	1	-		kc[1]		S
6602				1985	64	11	2	9		kc[1]		P
6603	419	3908	900	1985	45	19	1	8		kc[1]		D
6604	419	3908	900	1985	64	8	3	10		-		P
6605				1985						kc[11]		S
7273	428	3914	91	1987	21	12	2	7	6	kc[11]		P
7265	409	3912	91	1987	21	19	1	9	5	kc[1]		P
4984	412	3843	700	1981	31	17	1	12	D	B		D
4990	412	3843	700	1981	16				D	B		D
4991	412	3843	700	1981	86				D	B		D
5059	412	3843	700	1981	70				D	B		D
5060	412	3843	700	1981	180				D	B		D
6489									D	B		D
5055				1947	75	45	3	21	62	B		G
505B				1965	152	45	3	34	26	B		G
3360					134	58	4	46	182	B		G
4103					C107	C53	3	C43	114	B		P
3783					107	58	2	49	185	B		P
3588					107							D
KILIFI DISTRICT												
941	344	3919	271	1949	153		0		u	kt		D
TAITA-TAVETA DISTRICT												
70	332	3832	823	1938	92	92	4	9	157	B		
71	331	3823	826	1938	32	20	3	3	314	B		G
72	333	3824		1947	135	130	2	16	41	B		G
301	331	3823	823	1944	95	76	3	20	15	B		G
302	331	3823	808	1944	134	107	3	12	68	B		G
347	331	3823		1945	151	133	5	6	152	B		G
350	332	3823	823	1945	61	56	3	6	79	B		G
520	331	3821	920	1947	122	115	1	40	83	B		G
757	350	3853	414	1948	91	38	1	23	2	BB		D

Appendix 1 Continued

1 BH No;	2 LAT S	3 LONG E	4 ELEV m	5 YEAR	6 TD m	7 SWL mbgl.	8 NO Hoz	9 RWL mbgl.	10 Q lpm	11 LITH	12 S m	13 WQ
TAITA-TAVETA DISTRICT CONTINUED												
767					74			23	45	B		S
3588	344	3827	700	1969	109	32	1	26	0	B		D
4202	332	3823	822	1976	89	72	3	15	75	B		P
4203	331	3823	822	1976	50	34	2	5	113	B	5	P
4216	331	3824	868	1976	13	2	1			B		G
4217	332	3824	883	1976	15	7	1			B		G
4218	332	3823	822	1976	30	20	1	5	303	B	21.2	G
4219	333	3823	822	1976	35	16	2	5	453	B	25.4	S
4264	345	3837	610	1976	80	12	1	7	88	B	55.3	P
4724	331	3823	853	1976	65	9	2	6	100	B	49.1	G

Key:
1 Borehole ID Number
2 Latitude (to nearest whole minute of arc)
3 Longitude (to nearest whole minute of arc)
4 Elevation, metres above mean sea level
5 Year of completion of drilling
6 Total drilled depth, metres
7 Struck water level (? Principal water bearing zone), metres below ground level
8 Number of water bearing horizons
9 Final rest water level, metres below ground level
10 Tested yield, litres per minute
11 Bedrock aquifer:
- B Basement
- kt Taru Grits
- kc^{1} Lower Maji-ya Chumvi Beds
- kc^{11} Upper Maji-ya Chumvi Beds
- km Mariakani Sandstone

12 Drawdown at yield cited in 10 above, metres
13 Water quality, according to the following 'potability' scales:
- S Saline, non-potable
- P Potable (saline - fair)
- G Good - fair
- ? Unknown
- D Dry